Coral Reef Monitoring Manual

for the Caribbean and Western Atlantic

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FOREWORD

PURPOSE

We have developed this manual as a practical guide for scientists, students, and park managers who need to describe coral reefs or document changes in them over time. Although no book can substitute for a hands-on training program or on-site assistance from someone experienced in the technique you want to learn, the need for coral reef monitoring is urgent and the number of "experts" is still small. Many of those who need to begin a coral reef monitoring program have little choice but to get started on their own.

Like many ecological processes, changes in a coral reef may be slow and almost imperceptible over the short term, or highly variable from one year to the next. Consequently, looking at the long-term trends in the condition of coral reefs is vitally important. While this manual emphasizes monitoring the overall ecological and structural components of a reef, a more comprehensive program will also focus on the effects of human activities such as snorkeling, boating, diving, fishing, and shoreline development.

This manual cannot include all the monitoring techniques currently in use, or prescribe the single "best" technique to use in a particular situation. It does aim to explain some of the methods that have proved useful in coral reef monitoring programs. Some of these steps can be taken even if you have little or no background in ecological monitoring; for the more complicated procedures, you may find it necessary to refer to more detailed texts or to contact someone with more experience for guidance. Other manuals that provide guidance on coral reef monitoring procedures are listed in Part VI, "Information Sources."

As new or improved methods evolve, they should replace or supplement those described in these pages; you may develop some useful modifications of your own. Although it's not realistic to expect all coral reef monitoring programs to use exactly the same techniques, this manual is intended to encourage the increasing standardization of methods which can assist with discussion and comparison of data throughout the region.

ACKNOWLEDGEMENTS

National Biological Survey biologists, Caroline Rogers, Ginger Garrison, and Rikki Grober worked with National Park Service scientist Zandy-Marie Hillis to compile this manual. We are extremely grateful to Mary Ann Franke, a technical writer and communications expert, who volunteered to serve as editor and became one of the authors, contributing over six months of her time to this project. Her contributions have been invaluable and are reflected in the overall organization and layout of the text as well as its readability and clarity.

Draft versions of this manual were sent to over 40 scientists, park managers and other potential users in the U.S., Caribbean, and Australia for review (see list in Appendix D). The responses we received greatly enhanced the quality of this document and made it more comprehensive.

Special thanks to Jim Petterson (National Park Service) for assistance with the section on statistics, and to Manny Hemandez (University of Puerto Rico) and Richard Laydoo (Institute of Marine Affairs, Trinidad) for information on measuring currents. Betty Buckley (University of Rhode Island) helped us greatly with the section on nutrients and chlorophyll. Jim Beets, Alan Friedlander, and Joe Kimmel pleased all of us by revising the section on monitoring of fish assemblages after compelling themselves to come to a reasonable consensus. Jane Israel donated several hours of her time, coming to the rescue at the bitter end.

We wish to specifically thank Dominic Dottavio, formerly the Regional Chief Scientist with the NPS Southeast Regional Office, who recognized the value of long-term monitoring of coral reefs and provided funds for this manual and for our research over the last several years. Rob Milne, Director of the NPS Office of International Affairs, promised financial support for the production of this manual right from the start and has expressed his interest in preparing a Spanish translation.

We also wish to thank The Nature Conservancy and the World Wildlife Fund for assistance with publication and other costs. The Nature Conservancy has worked with us on several training sessions for marine park management. As part of a training program in the Dominican Republic, the World Wildlife Fund has prepared a reef monitoring manual in Spanish for non-scientists.

PHOTO AND ILLUSTRATION CREDITS

Cover photo taken near Little St. James Island, USVI, by Dick and Tina Burks. Other color photos by L. McLain (111-3, III-7), L. Lewand (III-6 top), P. Edmunds (III-6 bottom, A-1, A-2), C. Rogers (III-9), V. Zullo (III-14), W. Gladfelter (III-23), M. Taylor (III-34), and J. Porter (A-6). All black and white photos by H. Tonnemacher except for page III-11 by R. Halley. Figure on page I-8 courtesy of D. Hubbard. Original artwork by L. Smith-Palmer, Z. Hillis, K. Norfleet, and C. Rogers. Technical drawings by Katydids, St. John, USVI.

I. INTRODUCTION

Long-term monitoring is the repeated surveying of organisms or environmental parameters over time to help us understand a variety of natural processes. A monitoring program can provide information on the abundance of the biota, the diversity of the site, the condition of particular habitats, and changes in the environment. It may also enable us to predict the effects of human activities on ecological processes. Without long-term data, we cannot make appropriate decisions on whether and how a natural environment needs to be managed.

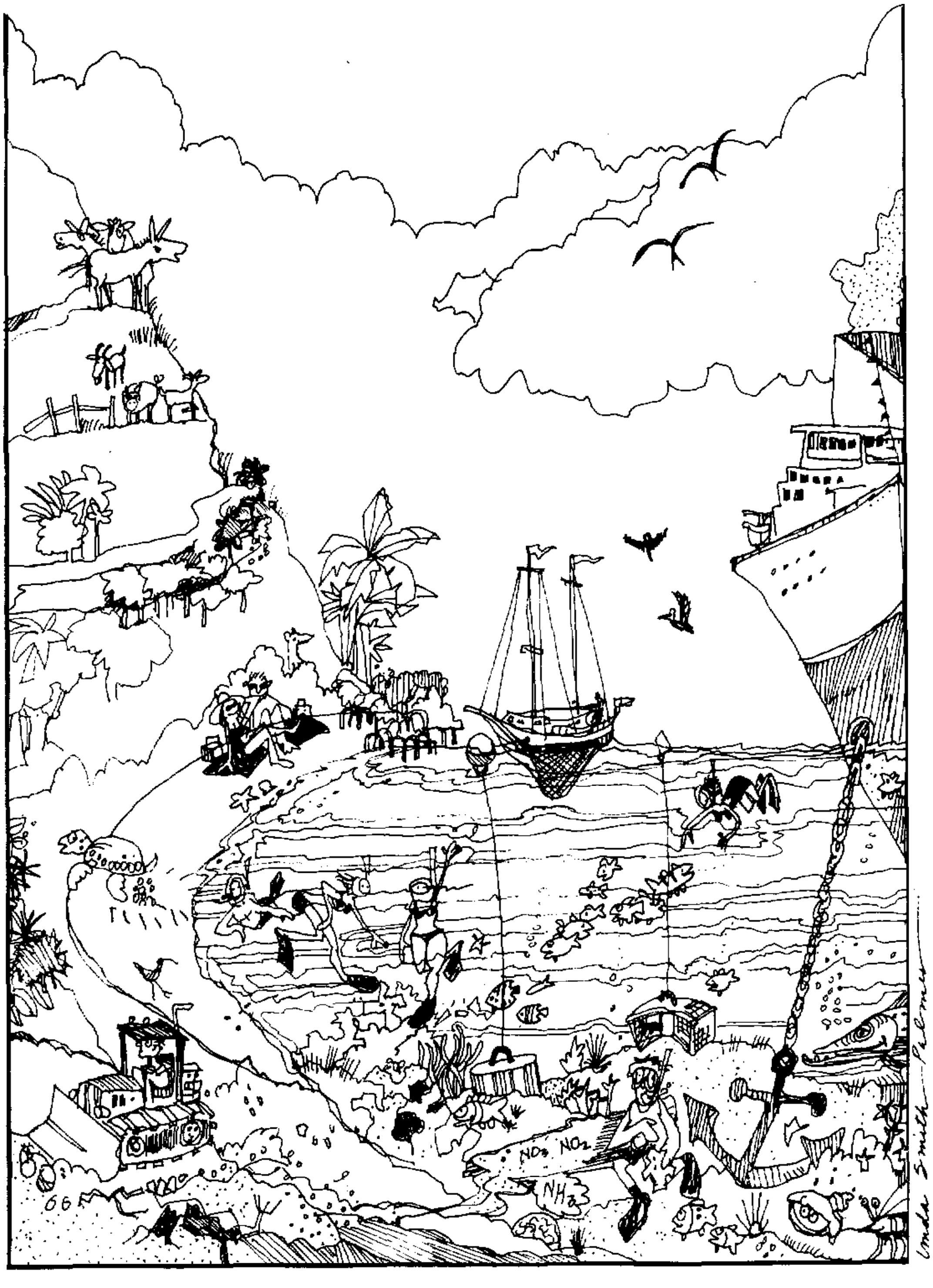
The terms “long-term research” and “long-term monitoring” are often used interchangeably. However, for many people, “research” implies manipulative, experimental activities, while “monitoring” refers to more routine data collection. This manual uses the term “long-term monitoring” with the recognition that biological and environmental monitoring are valid research activities. If you have questions about other terms used in this manual, you may find help in the Glossary, Part V.

GETTING STARTED

People interested in setting up monitoring programs often hesitate because they don’t know exactly how to go about it, or they lack sufficient money or staff. It’s important to realize that monitoring does not have to be complicated or expensive to be effective. To assist you in deciding which methods are within your budget, Appendix C provides approximate prices for equipment described in this manual.

In most areas, SCUBA is needed for effective access to the reef, but if your study site is shallow, snorkeling can provide much information. Most techniques used to sample hard-bottom communities involve using quadrats, transects, photography, videotaping, or a combination of these methods. Valuable data can be obtained through simple procedures. It’s better to jump in and start a limited but well thought-out monitoring program to gather baseline data than to wait until funding and personnel are available for a more comprehensive approach. The reef site you’re concerned about now may be quite different in another year.

If underwater photographs had been taken at established locations on Caribbean reefs over the last twenty years, we would have a good visual record of changes in the reef structure over time, including shifts in the relative abundance of plants and animals, and the percent of the bottom covered by living organisms -- information that would make it easier now to document the need for management action, or to distinguish the consequences of human activities from the changes due to natural processes.



Data on undisturbed or pristine reefs are especially valuable for comparison purposes, since concern about reef deterioration is often what prompts a monitoring program. Baseline data should be collected as soon as possible to characterize the site as it currently exists. You need to have some idea of the level of "normal" short-term variations that occur on the reef to distinguish them from significant long-term changes.

MONITORING OBJECTIVES

To set up an effective coral reef monitoring program, you'll need to start by asking: "What do we want to know?" Your objective may be quite general, such as "to determine the present status of the reef and natural rates of change," or it may be more specific, such as,

- to detect changes in abundances of a particular group of organisms;
- to discover possible cause-and-effect relationships;
- to determine if a specific management action is working (e.g., prohibition of spearfishing); and/or
- to measure the effect of both natural and human-induced stresses.

Some stresses or disturbances, like hurricanes or dredging, are of such magnitude as to cause immediately visible effects, while others, like over-fishing or pollution, may slowly undermine the health of the coral reef system and not be readily apparent through casual observation. An established monitoring program can help provide the necessary information to examine the effects of different stresses.

Some Stresses Affecting Coral Reefs

- Sediments from dredging or land clearing
- Nutrient influx from sewage
- Agricultural runoff (pesticides, nutrients)
- Boat groundings and anchors
- Physical damage from SCUBA, snorkeling, and swimming
- Shoreline development
- Industrial pollution
- Over-fishing
- Collecting for aquariums
- Oil spills
- Storms
- Disease
- Thermal stress
- Urban runoff

DESIGNING A MONITORING PROGRAM

Regardless of whether your objectives. are specific or general, they are the starting point in the design of your monitoring program and will help determine how you approach a question, the level of detail of your study or what questions you should try to answer. For example, a scientist may want to compare the condition of an undisturbed reef to that of a reef under stress from human activities. A developer may be asked to monitor reef conditions to determine if sedimentation rates are increasing as a result of dredging or upland development. Coastal zone managers may issue permits that require monitoring the effects of sewage effluent from a large hotel on a nearby reef. Dive tour operators may want to know if certain reefs are deteriorating from overuse. A fisheries officer may want to find out whether a ban on spearfishing is resulting in an increase in certain fish species.

In addition to having a clear understanding of your objectives, you'll need to answer the following questions to determine which monitoring methods will be most appropriate.

Designing a Monitoring Program

- What are our objectives?
- Where are we going to monitor?
- How often should we collect data?
- For how long should we continue collecting data?
- What methods will give us the best data?
- Who will conduct the monitoring?
- What methods are realistic for us, given the available time, money, equipment, people, and skills?
- How will we assure the data are of the highest quality?
- How will we analyze the data we collect?
- How will we store and retrieve the data?

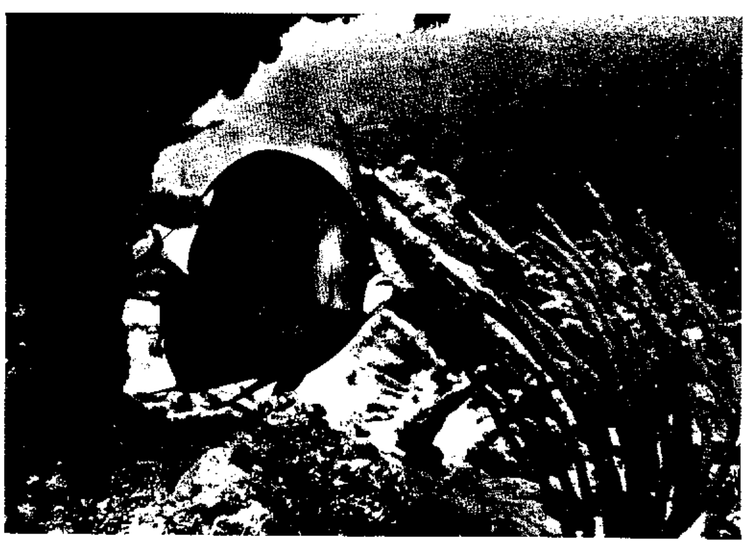
Despite the many references in this manual to quantitative data, it's important to keep in mind that qualitative data can also be useful. While quantitative analysis is preferred in academic circles and courts of law, you may find that qualitative information (e.g., photographs or videotapes of anchor damage) are sufficient to document the need for management action. Since no specific criteria have been established as to what constitutes optimum reef conditions, the best approach is to look for relative changes in a particular reef over time. To use your resources and time wisely, you'll need to devote considerable time designing your monitoring program.

BASIC MONITORING PRINCIPLES

Coral reefs are the most complex marine ecosystems on earth, and it is not practical to monitor all of the reef's animals and plants and their many interactions. However, here are some basic principles to keep in mind regardless of your specific monitoring objectives.

- To have historical data for assessing the extent and cause of changes, obtain information on:
  - basic environmental parameters such as temperature, salinity, and turbidity
  - the abundance of stony corals, octocorals, algae, sponges, and reef fish
- To have both qualitative and quantitative records at well-documented site locations, use a combination of photographic and transect or quadrat methods.
- Sample often enough to obtain documentation of changes in reef organisms of interest, but not so frequently that your sampling is destructive or inefficient.
- Establish procedures for long-term monitoring that are as free as possible from observer bias, and easily repeated by people who may be assigned the task in the future, and make sure the procedures are well-documented.
- Make sure your monitoring site is clearly defined and easy to locate, not only by you but by others who have never visited the site.

Using the monitoring techniques described in this manual can help you determine what changes are taking place on a coral reef; they may also provide evidence that more detailed study or management action is needed. But no monitoring program can provide a complete picture of a reef's condition, and the resulting data can only be as precise as the work done to obtain them.



DATA COLLECTION AND ANALYSIS

Data collection in the field can be fraught with difficulties, including logistical problems, equipment failures, and bad weather. Errors can result from not sampling in exactly the same place each time, from not clearly communicating instructions to new data collectors, or from mistakes in recording or transcribing the data. Here are some suggestions for increasing your chances of success.

- Preliminary testing and sound design should be included in any monitoring program. Before actual data collection begins, the methodology and equipment should be field tested under the conditions that will be found at the study site to make sure they can provide reliable and repeatable information.

- Long-term monitoring methods intended for use at permanent sites should be repeated within a short time interval, preferably by different observers, to assess the variation inherent in the method. Only when monitored values change by more than the "method variance" has a real change been detected. The variability between data collectors should be checked by having them record data for the same sample and comparing the results.

- A pilot study can also help determine the most effective sample size for obtaining the required information. For example, the optimal sample size can be calculated by plotting sample effort versus the number of species seen during your pilot study.

- Very basic data (date, time, location, depth, weather conditions, personnel, study site, species, method) may become critical at a later date so be sure to record it each time you do field work.

- All field notes should be reviewed as soon as possible after collection to make sure they are clear and complete, then photocopied for the tile, transcribed into a permanent data book, and entered into a computerized data base, with a copy of the file kept in a second location.

- Be careful that the demands of data collection don't use up your resources to the detriment of data management and analysis. In planning your monitoring program, be sure to allow for the time and expense needed to interpret and under stand the data you collect. The use of computerized data bases can greatly enhance and simplify data organization and statistical manipulation.

Underwater data collection: If you use a mylar sheet or a white slate, you can reuse it after transcribing the data and scouring it with cleanser. Some people prefer to use an opaque waterproof paper made by Nalgene as a permanent record, eliminating the need for transcription. You can secure the data sheets to the clipboard with rubber bands or elastics, and tie on your pencil. If you want a pencil that won't float away when it becomes untied, you can use Faber-Caste11 solid graphite pencils.

GENERAL SURVEYS AND MAPS

Most of the biological monitoring methods in this manual focus on censusing small sections of a coral reef (several square meters) and detecting changes over time. However, you may need to quickly survey a large area in certain situations. For example, a general survey of most or all of a reef will be essential if you want to assess storm damage or determine the appropriate boundaries for a new marine park. A preliminary survey can also be helpful in selecting a study area for a long-term monitoring program. The use of aerial photographs and a manta tow survey are two techniques used in making this kind of general assessment.

Aerial Photography

Aerial photographs provide a good starting point for a general survey of a coral reef. At a scale of 1:5000, many reef features are visible, and if the photos are taken during calm and clear conditions, water clarity may allow resolution of major features to a depth of 60 feet or more. Aerial photographs can be used to:

- Assist in selecting appropriate study sites.
- Document the distribution and extent of major marine ecosystems and the patterns of land and marine use which might affect these systems (e.g., construction of tourism facilities, clearing of hillsides, the increase in boats using an area).
- Provide a record of large-scale changes in shallow reefs and seagrass beds resulting from natural events such as storms or from human activities such as construction of marinas or other coastal development.

Groundtruthing**:** Aerial photos with high resolution can sometimes be used to identify major zones and habitats, although changes in the condition or abundance of reef organisms do not generally show up. You may need to SCUBA dive or snorkel to determine exactly what certain areas represent; the photograph may indicate only the location of drop-offs and the transition between zones. This field effort to verify the zonation patterns or habitat types in the photographs is referred to as "groundtruthing". (See "Manta Tow Survey," I-12.)

Mapping: ***You*** can create "base maps" of marine communities from enlarged aerial photographs (usually at least 10" x 10"). It is best to use professionally produced aerial photographs with a known scale. Photographs taken from a plane with a 35-mm camera are tine for general views; however, because they are usually not taken perpendicular to the surface, measurements of features are inaccurate. This is an important consideration if you are trying to produce a precise resource map.

To create a "base map", trace all distinguishing coastal and marine features onto drafting acetate from the aerial photograph. Using scale markers, such as a boat positioned a known distance from a landmark, will enhance the accuracy of the drawing. These base maps can be used to make rough estimates of the size of major habitats and zones. (See "Digitizing," III-34.)

Aerial View *Base Map*

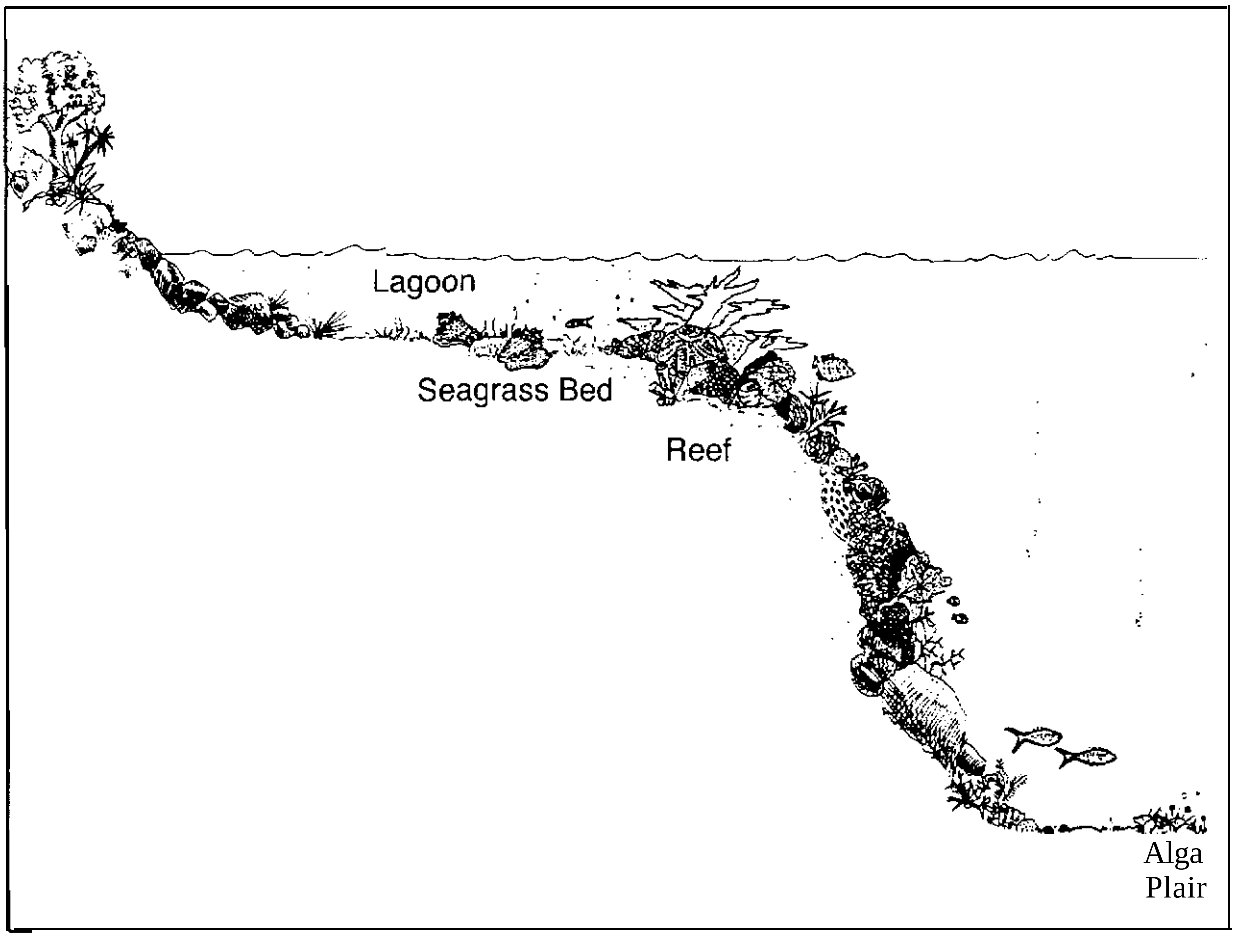
(Photo by NOAA, with map showing major features and study transects. Haystacks are patch reefs of broken and cemented elkhorn coral.)

GIS: Maps developed from aerial photographs can be used with a geographic information system (GIS), which enables you to use a computer to analyze large amounts of spatially located data, identify locations within a specified environment that meet certain criteria, and display the environment graphically or numerically. A GIS could be helpful in documenting changes in land use patterns (e.g., road building or land clearing), and large scale changes in the area1 extent of marine ecosystems, especially seagrass beds. A GIS is a powerful way to integrate and display large amounts of geographic data. However, geographic information systems are only as good as the data they are based on, and some of the data must be collected through labor-intensive field techniques.

To rind out what maps or aerial photographs may be available for the area you are interested in, contact the U.S. Geological Survey, the U.S. Coast Guard, the National Oceanographic and Atmospheric Agency (NOAA), the U.S. Navy, the National Park Service Geographic Information System in Denver, or the agency responsible for mapping and charting in your country or island, (e.g., Lands and Surveys, or Hydrographic Office).

Major Habitats and Reef Zones

It's often helpful to know how the reef you are interested in compares in its overall structure to other reefs in the region or to reefs referred to in scientific reports. Marine zones and habitats can be differentiated on the basis of their community structure and composition with consideration of relief, depth, location and size using the following definitions.



Marine Habitats

1) ***Shore or intertidal zone:*** The region between the highest water line and the mean low tide level.

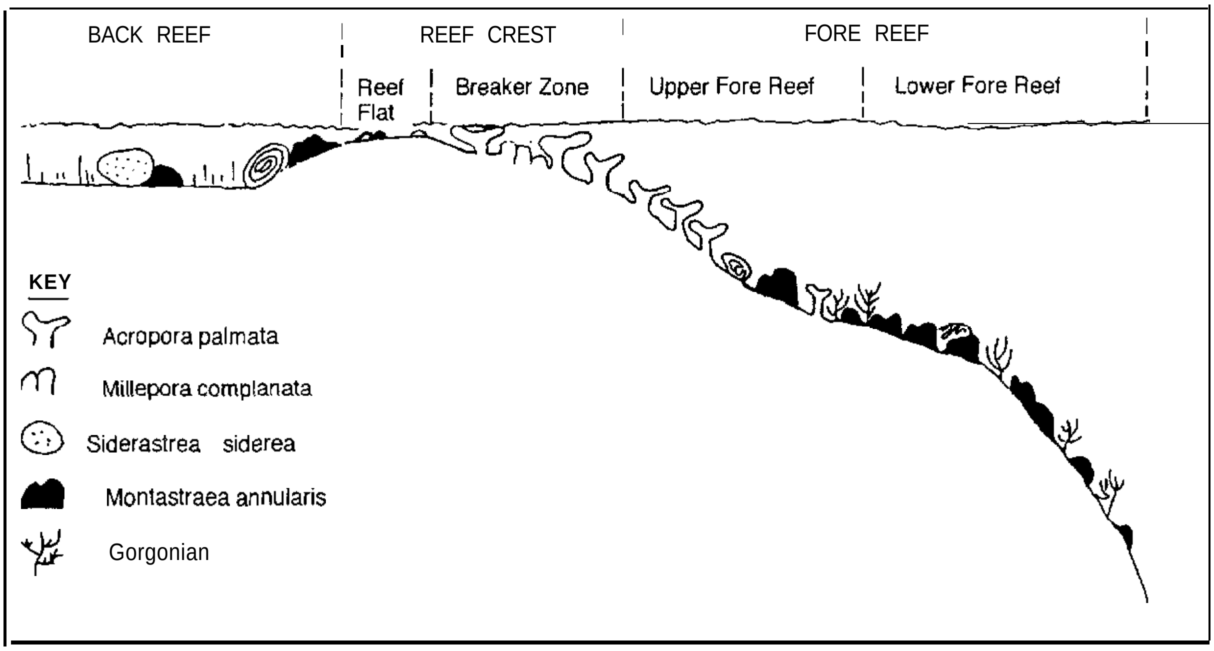
2) ***Sub-tidal bedrock:*** An extension of bedrock from the land or submerged boulder and rock deposits from shore.

3) Lagoon: A relatively calm area of water adjacent to the shore and landward of a barrier reef, or encircled by an atoll.

4) ***Seagruss bed:*** Areas with soft substrate dominated by one or more species of seagrasses, such as turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule* ***wrightii).***

5) *Reef* A major geomorphic feature generated from live coral and coralline algal growth that is an actively growing wave-resistant structure.

6) *Algal plain*: A deep water area (usually over 12 meters) dominated by algae, often including *Penicillus* spp., *Hulimeda* spp., and *Avrainvillea* spp.



Example of Reef Zones

Reef zones

A reef may include the following zones (not all zones are found on all reefs):

1) **Back reef:** the portion landward of the reef crest.

2) Reef crest: the shallow portion that separates the fore and back reef areas.

3) Reef **flat:** a platform of coral fragments and sand that may be exposed at low tide.

4) Breaker zone: the area most exposed to breaking waves, often dominated by elkhorn coral and tire coral.

5) Fore reef: area seaward of the reef crest, may include a buttress region dominated by boulder coral (coral "spurs" alternating with sand channels, or "grooves").

6) **Upper fore reef:** a shallow fore reef typically dominated by branching coral (*Acroporu palmata*) with high structural complexity.

7) **Lower fore reef: a** deeper fore reef, may be dominated by massive head corals with low structural complexity, or by gorgonians.

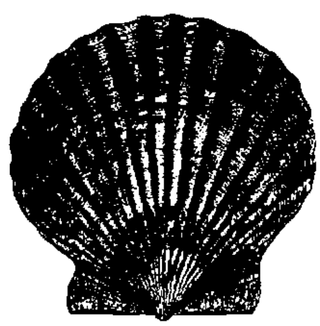
8) **Gorgonian-dominated pavement:** hardground dominated by gorgonians; occurs at a wide range of depths.

9) **Algal ridge:** a usually emergent barrier formed when crustose coralline algae deposit several layers of calcium carbonate on reef crests (found only in a few places in the Caribbean).

Types of Reefs

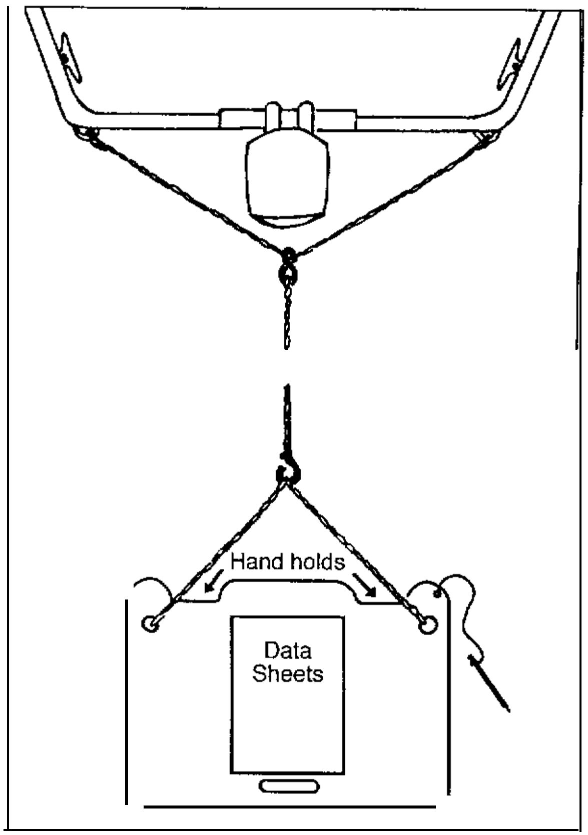
A reef may be classified as one of these types:

- ***Patch*** reef: An isolated complex of corals providing a major change in topography.
- Bunk ***reef:*** A large linear complex of corals located offshore that does not form a shallow water barrier.
- ***Barrier reef*** A reef separated from the shoreline by a deep lagoon or channel.
- ***Fringing reef:*** A reef bordering a shoreline.
- ***Shelf*** edge ***reef:*** A reef located at the edge of the continental shelf.
- ***Atoll reef:*** A reef in the open sea that forms a complete or partial ring around a lagoon with a fore reef that drops off into deep water.



Manta Tow Survey

Although a standard methodology for doing a manta tow survey does not yet exist, a snorkeler is typically towed over the reef by a small outboard motor boat, stopping periodically to record data.

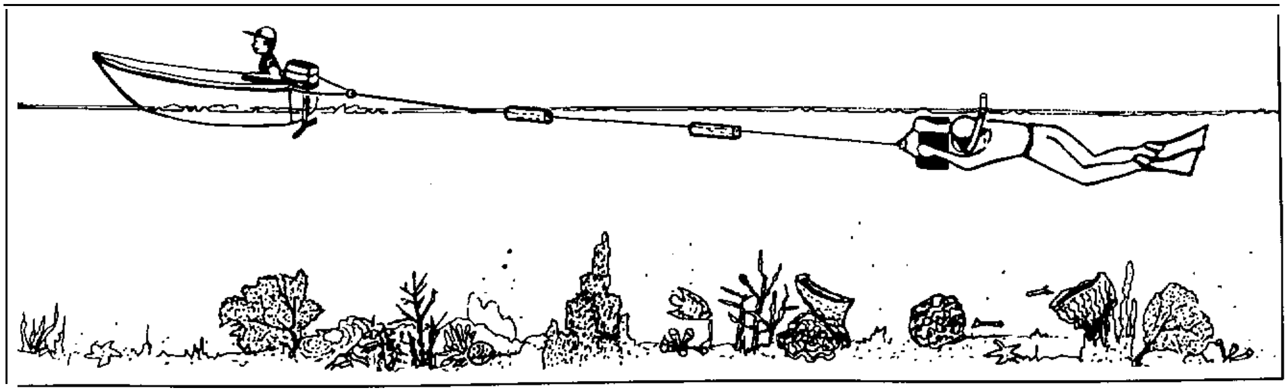


Manta Board

1) The observer holds onto a diving plane made from marine plywood about 2-cm thick, with two indented handle grips near each comer at the top and a single handhold at the bottom. Attached to the board is a data sheet and a pencil.

2) The boat driver, equipped with an aerial photo or map of the reef, tows the observer across the reef (3-5 km per hour during calm weather), making certain that all ecological zones of the reef are surveyed. It may be helpful to start at one edge of the reef and drive in a zigzag pattern across to the other edge; however, factors such as wind, currents and angle of the sun may determine the direction of the tow.

3) Using a waterproof watch to time the intervals, the driver stops the boat every 2 minutes so that the observer can record whatever data are needed for the survey. The driver records the location of each 2-minute tow, and begins the next when the observer signals readiness.

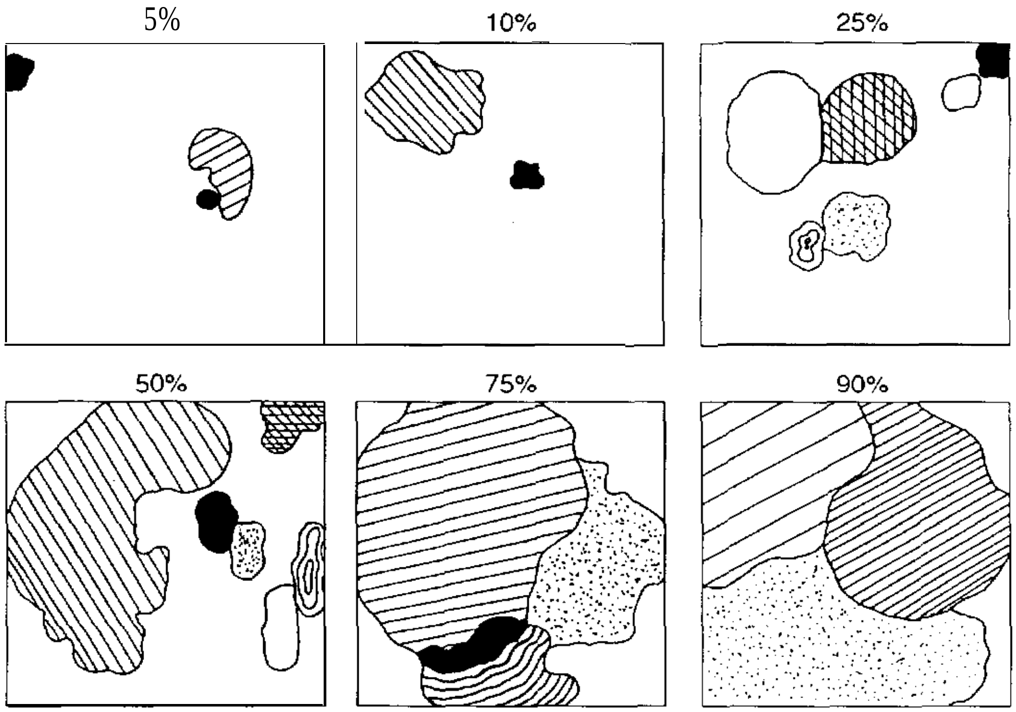


Manta Tow Technique

Sample Manta Tow Survey Data Sheet

Location:				Date:
Observer:				Time:
Tow	Percent Live Cover			Other Features
	Stony Corals	Octo-corals	Algae	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

The sample data sheet on the preceding page shows one way to organize information gathered during a manta tow survey. Your own sheet should reflect the particular purpose of your survey, e.g., looking for evidence of storm damage or coral bleaching. Estimating live percent cover (the percent of the bottom covered by living organisms) can be difficult, especially for a beginner, and in areas where organisms are unevenly distributed. You may also wish to note other features or specific organisms such as conchs or urchins. However, the number of different variables on which data can be collected will be limited by the observer's skill and experience.



Estimating *Percent* Cover

The precision of the manta tow survey is limited by the difficulty of visually assessing the dominant reef organisms while being towed behind a boat. Another drawback is that inappropriate areas may be surveyed (e.g., large areas of sand or deep water) because the tow path is controlled by the boat driver. However, the advantage of this technique is that it enables you to see the "representativeness" of separate study sites in the context of the wider variability of the reef environment.

Reference

Miller, J.W. (1991) "Scientific Diving Procedures," *NOAA Diving Manual*, National Oceanic and Manned Undersea Science and Technology Office, U Commerce, Washington, D.C., pages 8-28 to 8-30.

SITE SELECTION

The type and location of sites you select for your monitoring program will depend on your objectives and the monitoring methods available to you. You'll probably have to make some trade-offs because no site is likely to meet all your criteria. Here are some considerations:

Control sires: To assess changes resulting from human-caused stresses, try to include both "control" sites (undisturbed) and degraded sites. For example, if your objective is to determine whether pollution is damaging a coral reef, the study sites must be located near the source of the pollution with suitable control sites elsewhere. Locating a good control site can be difficult, because even reefs which are similar in species diversity and depth profile may differ in other significant ways. The most valuable data are obtained from repeated sampling at permanent sites over an extended period of time.

Represeniutive sites: If you are going to be sampling at selected sites to answer questions about a larger study area, some groundtruthing will be necessary to make sure your sites are representative in terms of depth, topography, and species diversity. The site with the best-developed reef structure is not necessarily the best study site. If coral cover is 80-90%, local abundances are more likely to decrease than increase over time even in the absence of major disturbances.

Reef complexity and "patchiness" complicate site selection for long-term monitoring. The term "patchiness" refers to the uneven, variable distribution of coral reef organisms in space, i.e., one portion of a reef may differ greatly from another portion in the amount of cover by reef organisms. ("Cover" refers to the amount of substrate occupied by an organism, often expressed as a percent.) In some cases, the zone with the largest percent cover by stony corals will not be the zone with the greatest number of species. In general, the larger the area over which the sites are distributed, the more representative the sampling.

Stratified sampling: If you are studying an area that contains a variety of depths, marine habitats, or other identifiable zones, it may be appropriate to stratify your study area into relatively homogeneous zones and choose a proportional number of sampling sites within each zone.

Random sampling: Your sampling within a selected study area or stratified zone must be random or most statistical tests will be invalid. Deciding on a means of site selection before visiting the reef can help eliminate the temptation to avoid an area that would be difficult to sample, or to use a "healthy-looking" site. You can assure random selection of quadrats (square or rectangular sampling areas), transects (linear sampling areas), or individual colonies by using:

- a random numbers table from a basic statistics book;
- random numbers in a phone book, with the last two or three digits used to select distances along a transect line or compass bearings from a given point; or

- a calculator with a random number generator that can provide pairs of numbers to indicate "x" and "y" coordinates for quadrats along a transect line. For example, the numbers 15 and 6 could designate placement of a quadrat 15 meters along a transect line and 6 meters to the south of it.

Once you have randomly selected a quadrat or transect, if you need to further subdivide it for sampling purposes, you can select sampling locations within the quadrat or along the transect on either a random basis (as described above) or a "systematic" basis, e.g., at the intersection points of a grid laid over the quadrat, or at 5-meter intervals along the transect.

Repeat Sampling: Either temporary or permanent sites can be used to assess change over time in marine communities, but the results have different statistical implications. Sites that are randomly selected each time are considered inherently less biased because the "representativeness" of a permanent site can always be questioned. However, sampling done at different sites each time may not be sensitive enough to measure change because of patchiness in the reef. In addition, the use of temporary sites requires more samples to give the same level of statistical confidence as provided by repeat sampling at permanent sites. Permanent sites are generally recommended for the long-term monitoring described in this manual because they offer the greatest amount of information, consistency, repeatability, and reliability.

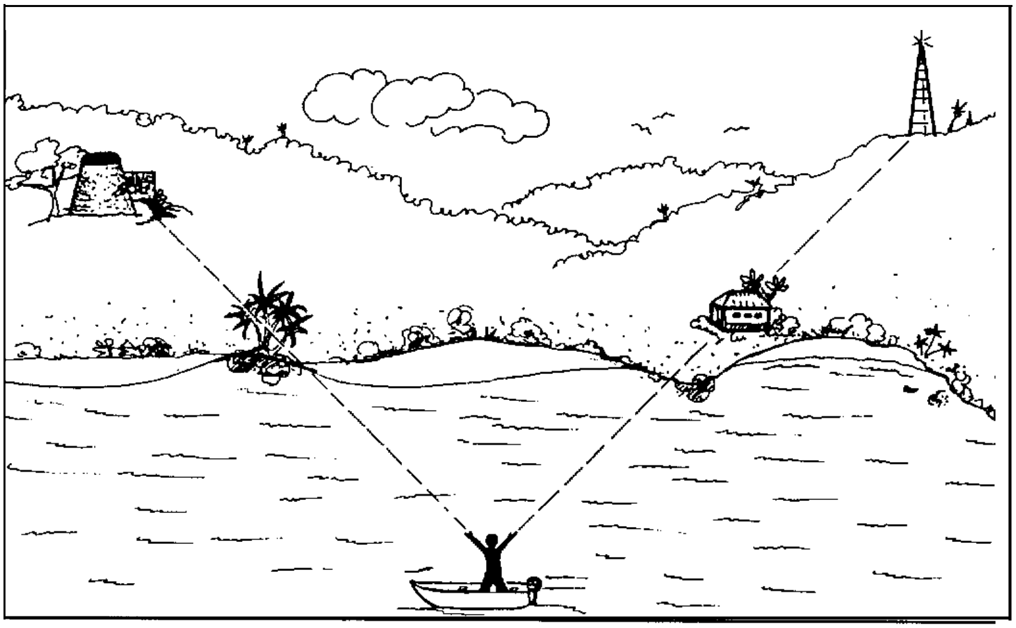
Marking the Site

Once you've selected a permanent site, you need to carefully mark and document its location so that you can easily find it again.

Reference markers: Reference markers should be clearly visible from a distance. Re-bar, brass, or survey stakes may last for several years, but should be checked regularly, as even durable materials will deteriorate eventually. A survey stake is a copper-covered steel marker with a bronze head. They come in several lengths, with 24", 30", and 36" the most useful. Reference stakes can also be made from square stainless steel tubing; tubing l-2 inches in diameter with 1/8 inch wall thickness usually holds up well. Stainless steel eye pins can also be used. (See "Materials and Suppliers", Appendix C.)

Installing markers: Driving nails, spikes, rods, or pipes into the substrate with a sledge hammer or pile driver may work in some locations, but is impractical or futile in others. You can install markers in hard substrate using a pneumatic drill with a carbide masonry bit powered by air from a SCUBA cylinder or a surface-deployed compressor. A few pointers: pneumatic tools are noisy and require downward force, so the diver will need to be heavily weighted and wear ear protection and a thick wetsuit. A pneumatic drill needs careful maintenance to ensure safe and effective operation.

Drilling with compressed air becomes less efficient with increasing depth. Hydraulic systems provide a more powerful, less noisy, but more expensive alternative. Once the holes have been drilled, the stakes can be cemented into place using hydraulic cement mixed on the surface and brought down in ziplock bags or sealed tupperware containers.



Recording the Location

Record the location: To find the site easily again in the future, you need to record its location as precisely as possible. Here are some suggestions:

- The generally preferred way is to photograph at least two pairs of conspicuous and permanent landmarks that are in the same sight line from the boat and at least 90" apart. For example, you might see a red house behind the highest point of a rocky outcropping on the shore in one direction, and a water tower behind a conspicuous tree in another direction. To return to the site, you find the place where these features are lined up.

- If you cannot find pairs of lined-up landmarks, you can photograph at least three single landmarks and record the compass bearings to them from a boat at the site. Again, the wider the angle between landmarks, the better your documentation.

- If you select landmarks that are found on a map, you can use your compass bearings or pairs of lined-up features to record your site on the map.

- Recording the depth at the site can help confirm correct relocation, especially if used in combination with compass bearings or pairs of land features.

- You can record or photograph any conspicuous coral colonies or other features to help you navigate underwater.

- You can attach a submerged buoy to a piece of dead coral with flagging tape. (If you attach it to a stake, its movement in the water may loosen the stake.)

- If you have a handheld GPS (Global Positioning System), you can determine the coordinates of the site's latitude and longitude. However, the accuracy of a GPS varies from ± 3 to ± 50 meters, depending on the specific instrument and whether there is a base station nearby.